MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 3, 2016/2017

ENT4066 – NANOELECTRONICS MATERIALS AND DEVICES
(NE)

29 MAY 2017
9:00 – 11:00 A.M.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This examination paper consists of 5 pages with 4 questions only.
2. Answer all questions.
3. Please print all your answers in the Answer Booklet provided.

QUESTION 1

(a) Given that the energy of a free electron in a bulk (3D) semiconductor is :

$$E = \frac{\hbar^2}{2m}\left(k_x^2 + k_y^2 + k_z^2\right)$$

(i) What are the energies if the electron is confined in 2D, 1D and 0D of nanostructures ? [3 marks]

(ii) Plot the density of electron states per unit energy and per unit volume for bulk (3D), surface (2D), line (1D) and dot (0D). [4 marks]

(b) Compare and contrast the electron transport behaviour in conventional and mesoscopic devices in terms of device length (L) with respect to the electron mean free path (l_e), phase coherence length (l_ϕ) and Fermi wavelength (λ_F). [6 marks]

(c) (i) With aid of a simple diagram, describe the laser generation of nanoparticles (NPs) in liquid. Explain also the effect of photo-fragmentation. [4+1 marks]

(ii)Figure Q1(c) shows the optical absorption characteristic of laser-generated silicon NPs,

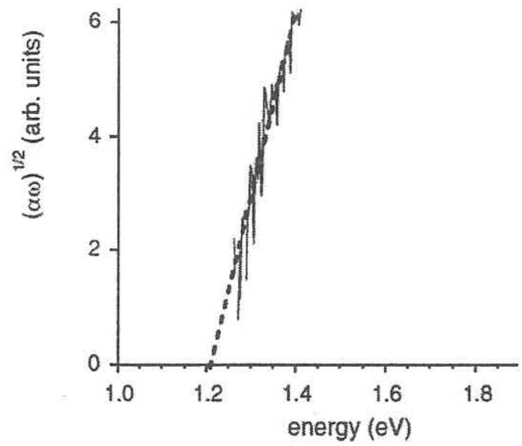

Figure Q1(c)

which is governed by $\alpha(\hbar\omega) \propto \omega^{-1}\left(\hbar\omega - E_g\right)^2$ where E_g is the bandgap energy. Obtain the bandgap energy, E_g from Figure Q1(c). [2 marks]

(iii) The bandgap energy E_g of Si NPs depends on their diameter (d), given by

$$E_g = E_o + \left(\frac{3.73}{d^{1.39}}\right)$$

where E_o = 1.12 eV. Calculate the average diameter, d. [3 marks]

(d) Give **FOUR** key issues in the preparation of high-quality nanoparticles. [2 marks]

Continued.....

QUESTION 2

(a) A single wall carbon nanotube can be formed from a two dimension sheet of graphene, with chiral vector :$C = na_1 + ma_2$ where $a_1$and a_2 are the graphite lattice vector and m, n are integer. Show that the diameter of the single wall carbon nanotube formed (D) is given by

$$D = \frac{\sqrt{3}a_{cc}\sqrt{(m^2 + n^2 + mn)}}{\pi}$$

where a_{cc} is the carbon-carbon bond length (1.42 Å). [7 marks]

(b) (i) Find the diameter and the chiral angle of a single wall carbon nanotube with (n, m) = (6,5). [3 marks]
(ii) Comment on the structure, chirality and conductivity of the nanotube in b(i). [3 marks]

(c) Discuss why carbon nanotubes are promising candidate in nanoelectronics; and the challenges faced in realization of carbon nanotubes for electronics. [4 marks]

(d) Describe the types of bonding found in graphene. How do they affect the properties of graphene? [4 marks]

(e) With the help of the energy versus wavevector (E-k) diagram, explain the distinct carrier transport of graphene as compared to a conventional 2D semiconductor. [4 marks]

Continued.....

QUESTION 3

(a) (i) Name the three models of scaling for Field Effect Transistor (FET) based on the factor α, as shown in Figure Q3(a). Briefly describe the basic ideas and violations in these three scaling rules. [6 marks]

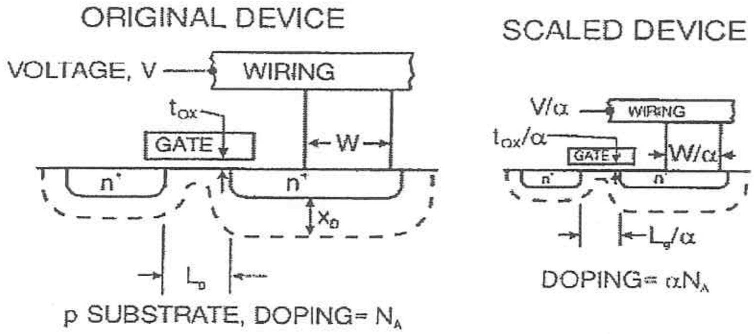

Figure Q3(a)

(ii) In scaling down the FET, the channel becomes short as compared to its thickness, briefly discuss a few 2-D, or the ratio of channel length-to-thickness effects. [4 marks]

(b) (i) Figure Q3(b) shows the gate current density as a function of the gate voltage for nano-CMOS, briefly explain the current-voltage characteristic.

[3 marks]

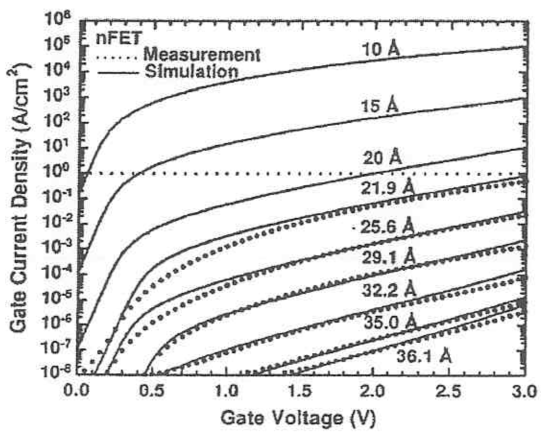

Figure Q3(b)

(ii) High-k dielectric materials have been considered to replace the conventional SiO_2 as the gate insulator in nano CMOS. Briefly describe the requirements for choice of high-k dielectric. Name one successful gate-insulation material and sketch its integration scheme. [6 marks]

(c) Comment on the *floating body effects* (FBEs) in partially-depleted (PD) and fully-depleted (FD) silicon-on-insulators (SOIs) respectively. [6 marks]

Continued.....

QUESTION 4

(a) Electrical conductivity in bulk metals is continuous because there are an enormous number of electronic states in the conduction band of metals, but this is changed at nanoscale.

(i) With simple diagrams compare the current-voltage characteristic of a normal capacitor and a quantum-dot capacitor charging. [2 marks]

(ii) What is Coulomb blockade? [2 marks]

(iii) The capacitance of a nano-sized island used in a single-electron transistor (SET) is given by $C=2\pi\varepsilon\varepsilon_o d$, where d (12 nm) is the diameter of island, $\varepsilon=4$ and $\varepsilon_o = 8.85\text{x}10^{-12}$ F/m. Calculate the temperature limit for SET effect. Given that Boltzmann's constant is $1.38066\text{x}10^{-23}$ J/K. [4 marks]

(b) Design a Coulomb-blockade, gate-controlled single-electron transition using the silicon-on-insulator substrate. [4 marks]

The drain and gate capacitors are given by $C_1 = 1.293\times10^{-17}\,F$ and $C_G = 1.724\times10^{-18}\,F$. If the temperature T is close to zero and a gate voltage $V_G = 0$ is applied, what is the value that V_{DS} must exceed to overcome the Coulomb blockade ? [3 marks]

(c) (i)With aid of simple energy band diagrams, explain the operating principle of a double-barrier resonant-tunneling device, in particular how does it differs from conventional tunnelling. [4 marks]

(ii) Design a resonant tunnelling device made from a double AlGaAs barrier, indicate how the energy-band structure for enabling a resonant tunnelling device. [4 marks]

(iii) Name and describe an application for resonant tunnelling diode. [2 marks]

End of Paper